I. TITLE OF REPORT: A Methodology for Small Scale Rural Land Use Mapping in Semi-Arid Developing Countries Using Orbital Imagery: Part III: Review of Land Use Surveys using Orbital Imagery in the U.S.A.

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SUMMARY OF SIGNIFICANT RESULTS

No comprehensive review of current research dealing with land use surveys involving orbital remote sensing techniques has been published since Nunally (1974) considered investigations up to 1972. The review treats techniques of preprocessing, interpretation, classification and ground truth sampling. It has shown up the need for a low-cost, low-level technology, viable, operational methodology to replace the emphasis given in the U.S.A. to machine processing, which many developing countries cannot afford, understand nor implement. Such a proposed methodology will be given in the final contractors report, to be submitted to NASA in October 1976.

(All references in this paper can be found in the bibliography of the final contractor's report)

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3. REVIEW OF LAND USE SURVEYS USING ORBITAL IMAGERY *IN THE U.S.A.*

3.1 INTRODUCTION

As far as can be ascertained, no comprehensive review of current research dealing with land use surveys involving orbital remote sensing techniques has been published since Nunnally (1974) considered investigation up to and including 1972. His article included details of research that only involved preliminary assessment of Landsat data. Therefore, it is apparent that this type of review is presently necessary in order to bring together the main "threads" of world-wide research but it is beyond the scope of this present study to detail all of the wide-ranging applications that have emerged during the last three years. The major consideration will involve the utilization of imagery obtained from orbital multi-spectral scanners in small scale rural land use surveys in developing countries, However, in order to avoid the confusion that often occurs in current terminology it is necessary to indicate the precise meaning of land use surveys in the context of this research.

3.1.1. SMALL SCALE RURAL LANDUSE SURVEYS

The term "small scale rural land use survey" refers to the grouping of the spatial distribution of land use into distinct categories at a particular time. Due to the small scale (i.e. 1:200,000 or smaller), urban areas may be distinguished but are usually not examined in depth. The major emphasis is placed on the uses to which man assigns various parts of the rural areas. The overall aim is not to produce a detailed description of all the items that give a certain region its particular character or try to offer a detailed explanation of the factors affecting the spatial distribution of land use both within and between different parts of the region. Generalised land use categories are determined rather than a complete enumeration which normally involves the detailed collection and description of land-use characteristics in terms of type and areal extent. Thus, the final small scale rural land use map is a generalised cartographic representation of the ways in which man has utilised the surface of the earth at a particular time and these uses have been influenced by the interaction of environmental, technological, economic, social and political factors but no attempt is made to explain the extent of this interaction.

The level of accuracy of interpretation of land use from orbital imagery is a function of the type and quality of imagery, scale, spatial resolution, time of acquisition and the interpreter's knowledge of the area. These, in turn, affect the complexity of the land use classification system that can be used and, in fact, affect the whole nature and approach of the survey. The dominant purpose behind the production of small scale rural land use maps is to produce rapid cartographic descriptions of large parts of the Earth's surface. These maps may be used for a variety of purposes such as the initial reconnaissance of an area that has been poorly mapped or, in other areas, as a record of the land use characteristics of the region at a particular time. Consequently, there is a marked difference between the small scale land use surveying techniques used in this study and those used in other types of land use surveys e.g. land use inventories, integrated land systems surveys and landscape studies.

3.1.2. RURAL LAND USE INVENTORIES

The major aim of rural land use inventories is to carry out a complete enumeration of all the land within a particular region. They provide detailed information about the type, acreage and distribution of land use that is essential for efficient regional planning and management but they are time-consuming and expensive to produce. Originally, data were collected by census interviews or field mapping as well as information obtained from various statistical agencies, mail questionnaires, and specific sample surveys. Later, vertical aerial photographs were added to the data sources and permitted the rapid location and quantification of certain land use characteristics (Coppock, 1963; Luney and Dill, 1970). Unfortunately, the current level of automatic interpretation and the relatively poor spatial resolution and subsequent small-scale mapping limitations of orbital multi-spectral scanning imagery cannot provide the detailed information required for land use inventory surveys. This is particularly obvious with LANDSAT 1 and 2 data where spatial resolution is approximately 80 metres and the identification and classification of rural land use can only be established under relatively broad categories with large fields and not individual small fields or small holdings. However, orbital imagery can provide valuable assistance in the form of rapid synoptic coverage of large regions which cannot be achieved by conventional vertical aerial photography. Many attempts have been made to develop computer assisted automatic land inventory systems using orbital imagery with varying levels of success. Roberts (1975) reports that considerable improvement in both data acquisition and processing will be necessary before orbital MSS data can be used operationally. The following references provide a general cross-section of the nature of this type of investigation:-

Allen (1975), Bizzell et al (1975), Bankston (1973), Chase et al (1974), Carlson et al (1974), Draeger and Benson (1972), Hall et al (1974), Haralick and Shanmugam (1974) Hoffer (1975), Horton and Heilman (1973), Johnson and Coleman (1973), Jones, C. (1974), Kriegler et al (1972), Lundelius et al (1973), Mooneyhan (1973), Mower (1972), Owen-Jones (1975), Ratti and Capozza (1974), Richardson et al (1974), Roberts (1975), Savigear (1975), Shelton (1974), Simonett (1974), Sweet and Pincura (1974), Thomson (1973), Tunnetti and Montzer (1974).

3.1.3. INTEGRATED LAND SYSTEMS SURVEYS

An integrated land systems method was developed by the Australian C.S.I.R.O. Division of Land Research in order to carry out preliminary surveys of land resources in the Northern Territory, N.W. Queensland, the northern part of Western Australia and Papua (Young, 1973). Details about the concepts of these surveys have been well-documented by Haantjens (1965) and Christian and Stewart (1968). According to Blake and Paijmans (1973) a "land system" was initially defined as an area or group of areas throughout which there was a recurring pattern of topography, soils and vegetation. But, as the vertical aerial photographs became readily available they became the major information source for the recognition and delineation of the land systems. "The recurrence of a number of (land) units within a land system in a regular pattern gives rise to a distinctive pattern on the aerial photograph" (Christian and Stewart, 1968). The surveys have been accomplished by a team usually consisting of a geomorphologist, plant ecologist and pedologist who delineated preliminary land systems on the basis of air photo interpretation which was followed by field checking. After the field check, the data from the team members was integrated and descriptions of the systems and their sub-systems (or land units) together with an assessment of their capabilities and resources were published.

The C.S.I.R.O. integrated land systems approach due to its rapidity and comparatively low cost has been adapted and used in a number of countries and the British Directorate of Overseas Surveys Land Resources Divisions use essentially the same method for planning agricultural development in extensive, unsurveyed regions (Mitchell, 1973). Similar methods of landscape evaluation have been developed in U.S.S.R. and Canada since World War II but use different terminology.

A later adaptation of the C.S.I.R.O. method has been the landform type method used in East Papua which places more emphasis on landforms and rock types which are mapped by the geomorphologist mostly independently from the plant ecologist. The same survey team structure is maintained as well as the basic techniques using aerial photography and field data (Blake and Paijmans, 1973). Wright (1972) also maintains that goemorphology can provide the necessary classi[illegible]tory framework which will permit the team specialists to co-ordinate and extrapolate their finding and he has presented a detailed account outlining the principles and problems involved in devising the framework.

Criticisms of the land systems approach have included the comments that the technique of mapping patterns from aerial photographs is too subjective as it mainly depends on the available field data and the bias of the individual members of the survey team. Also the systems and sub-systems defined by the survey team are not classifications in the strict sense and do not rely on prescribed objective procedures for the grouping of categories. This aspect, the critics claim, affects the reliability of comparing land systems in one area with those in another area if they have been determined by different survey teams. Another criticism of this approach has been levelled at the concentration on the description of the physical environment compared to the brief evaluation sections which contain no economic analysis. Furthermore, Young (1973) reports that the technique has been condemned by Davidson (1965), also on economic grounds, because he believed that the teams were collecting information which was useless as an investment guide and, therefore, a waste of government money. Young also discusses an argument that ecology should replace geomorphology as the basis for resource assessment so that the effects of development on the ecosystem could be predicted. But he agrees that, although there is merit in this approach, the development of a versatile survey procedure based on an ecological method has not yet eventuated. Similarly, Rogers (1971) stressed the need for an ecological approach to resource surveys but did not offer any advice on how it could be implemented.

At the present time, it appears that orbital imagery has not been used to any extent in integrated land system or landform type surveys. Howard (1974) has stated that "the potential contribution 66 satellite imagery to integrated surveys in developing countries is only beginning to be appreciated". He claims that the major problem has been due largely to the resolution and small scale of the orbital imagery and the difficulty of identification and he has proposed a list of hierarchical land-units that could be incorporated in integrated surveys using orbital imagery.

The problem of identifying land units has been considered by van Generen (1972, 1973) who suggested that meaningful boundary delimitations can be made on orbital imagery using various image enhancement techniques. These have been incorporated into an experimental procedure involving the analysis of imagery using conventional visual photo-interpretation methods and tested in the Murcia region of S.E.Spain.

3.1.4. SUMMARY

Overall, the integrated land systems surveys have played an important role in rapidly providing descriptions of underdeveloped regions. But, the criticisms about which discipline should be emphasised e.g. geomorphology, ecology, economic and the subjective nature of the description of land systems do not directly affect the nature of the delineation of boundaries in small scale rural land use surveys being considered in this investigation. The major concern is to identify and classify the various ways in which the surface of the land is being utilised at a particular time rather than a complete enumeration or description of the region. However, it is interesting to note that Alexander (197[illegible]) has reported that the CARETS (Central Atlantic Regional Ecological Test Site) investigators of the Geographic Applications Program, U.S. Geological Survey have set up a basic hypothesis of interdisciplinary regional analysis in which land use at least in a highly developed region, is an indicator or resultant surface expression of several interacting environmental processes. Also they claim that of all the environmental and socio economic processes which contribute to the surface patterns, land use is the one with data sets most accessible to Landsat sensors. On this basis, the CARETS investigators believe that remote sensor derived data sets and land use should become the "basic data entry into a regional information system to serve regional planners and land managers". They also believe that the dividing of LANDSAT data into sub-sets or photomorphic regions may provide a very economical sampling strategy for selecting sites for more detailed measurements if many other environmental variables prove to be correlated with the similarity of patterns on LANDSAT imagery.

The over-riding problem in small scale land use surveys based on orbital imagery appears to be the lack of a detailed methodology which outlines the most satisfactory techniques that could be used in pre processing, interpretation, classification and the establishment of ground truth and would be appropriate for use by countries which do not possess sophisticated equipment. Consequently, it seems that the most logical approach in reviewing the existing "state of the art" would be to consider, in a general sense, a cross section of investigations and applications that have been used in various studies around the world.

3.2. REVIEW OF RELEVANT UNITED STATES RESEARCH

3.2.1. INTRODUCTION

Small scale land use surveys utilising MSS Landsat imagery has been undertaken in many parts of the world using a wide variety of techniques. The majority of these surveys have been carried out in the United States or by United States organisations on behalf of foreign government or organisations. However, the situation in the United States is not typical of the rest of the world, excluding North Western Europe. Most countries have not had the advantages of extensive and up to date background information in the form of topographic maps, agricultural statistics services, existing land use maps and readily accessible aerial photography. Also, there has been very active concern in the United States, during the last decade or so, with the wide ranging effects of population pressure on the environment, including the encroachment of urban expansion on rural areas, the intrusion of recreation pursuits on relatively untouched regions as well as the many forms of environmental pollution. (Anderson & Hardy (1971, Bale and Bowden (1973), Place (1973).

This concern over the future of the envieonment has led to the introduction of legislation at State and local government levels which has either directly or indirectly, instigated a series of land use surveys, (Braun et al, 1973; Nunnally, 1974; Carlson et al, 1974). Furthermore, since 1970, a number of legislative proposals at Federal government level have been introduced including "The Land Use Policy and Planning Assistance Act of 1973" which aimed to develop and implement a natural land use policy, in association with State and local bodies, which would incorporate environmental, aesthetic, economic, social and other factords The Act was not passed in the House of Representatives but it acted as a catalyst which activated a host of investigations thoughout the country by Federal, State and local government organisations as well as many tertiary institutions (Lindgren and Simpson, 1973; Shelton and Hardy, 1974).

Some of the main problems foreseen in the implementation of the new Federal Act were the recording of the land use charatteristics so that future planning could operate from a suitable base and the development of a method which could rapidly monitor land use changes. With the launching of ERTS 1 (LANDSAT) in July 1972 a vast amount of environmental information becmme available every 18 days and this led to a wide variety of interpretation, classification and map-making investigations. Many of these were essentially computer-based inventory techniques which have been discussed briefly in Section where a broad range of articles on descriptions and criticisms have been listed. However, most of these investigations have not reached the operational stage.

3.2.2. GENERAL REVIEW

A number of studies have investigated the extent to which conventional image interpretation and computer-based analysis techniques could be applied to LANDSAT data in order to detect, classify and measure the extent of land use over large areas (Dornbach and McKain, 1974; Brown et al, 1973, Wilms, 1973.) But, as mentioned previously, one of the aims of this research is to consider uncomplicated and inexpensive techniques that may be incorporated into a methodology that could be used in countries which lack sophisticated equipment and highly trained staff. Therefore, the following discussion will concentrate on presenting a general outline of a number of relevant United States research project which have utilised LANDSAT data to produce small scale rural land use maps. However, as stated earlier, many of the procedures adopted in most of these studies cannot be applied in other countries because the U.S. researchers have had the advantage of extensive background material and in some cases, special high and/or low altitude sub-orbital photography was flown to coincide with the acquisition of the orbital imagery. An attempt will be made to outline the level and direction of the pre-processing, interpretation, classification and ground truth procedures adopted.

One series of investigations in the Central Coastal Region of California by Estes, Thaman and Senger, Geography Remote Sensing Unit, University of California, Santa Barbara before and after LANDSAT imagery became available has shown how small scale orbital and aircraft imagery could be used to investigate and monitor regional land use changes. (Estes and Senger, 1972). In later studies, the major emphasis was placed on the establishment of a detailed data base of the region and a classification system was devised for the preparation of land use maps using high altitude colour photography and selective ground reconnaissance (Estes, 1973). This background material was then used to evaluate the information content of LANDSAT imagery with regard to land use mapping and it was found that the classification system required modification. In addition, they found that the spatial resolution of the imagery placed limitations on the amount of detail that they could identify. The smallest area classified was 2.641 sq. km. which represented approximately 0.026 sq. cm. on the image at a scale of 1:1,000,000. But they claimed that the resolution restrictions could be off-set to a large extent by the synoptic overview provided by each Landsat frame.

In a recent report, Estes, ~~Thoman~~ Thaman and Senger (1974) outlined the procedure that they adopted in their analysis of Landsat data and provided some guidelines that could be incorporated in the development of a detailed methodology for the production of small scale land use maps employing unsophisticated techniques. These suggestions were derived after investigations were carried out using NASA 9½" x 9½" (1:1,000,000) black and white transparencies of at least two spectral bands (usually 5 and 7) and 10X enlargements of selected portions of the Landsat images which were optically enhanced by magnifiers and stereoscopes. They believe that, after the preparation of a suitable classification scheme and the establishment of an adequate data base, the following stages should be followed:-

" (i) an initial phase during which the image interpreters familiarise themselves with the unique scales, resolution, contrast and tonal and textural characteristics of Landsat imagery

(ii) preliminary interpretation of the imagery for representative test sites to determine the interpretability and classification related information content of the Landsat imagery

(iii) evaluation and modification of classification schemes based on the preliminary studies

(iv) completion of data base maps for the entire California test site

(v) the application of Landsat data to ancillary problems with particular focus on interfacing with and trying to encourage resource management agencies and other user groups to attempt to utilise Landsat type data on an operational basis."

They concluded that Landsat data could be a valuable source of environmental resource information but the comparatively poor spatial resolution creates problems when a wide range of environmental phenomena are located in small areas. But, as they emphasised in previous reports, the synoptic overview and the relative ease of repetitive monitoring and up-dating offer compensating advantages.

The Geographic Applications Program of the U.S. Geological Survey (GEO GAP) has initiated a series of investigations involving ~~Landsat~~ LANDSAT imagery. One study has considered the Phoenix quadrangle, Arizona and, initially, the project was designed "to make effective use of past experience in making land use maps and collecting land use information" and to investigate ways in which small scale orbital and aircraft imagery could be utilized (Anderson and Place, 1971). The first specific objective was to make a small scale land use map (1:250,000) using Apollo 9 and aircraft imagery using at least eight major categories and several sub-categories which could be identified and mapped. The second major objective was to develop a "geographically oriented data bank of land use information" that could eventually be digitised and the computer would "print out on all land use maps, land use information in tabular form and to make several different kinds of analyses of land use".

The Phoenix quadrangle was chosen for a number of reasons including the fact that considerable recent analytic research had been carried out by the U.S. Geological Survey and a large amount of current imagery was available. Also, the clear skies and low latitude ensured that additional imagery from future manned and un-manned satellites should be available.

During the initial investigations, imagery was mainly obtained using conventional aerial cameras with a variety of film-filter combinations but considerable emphasis was placed on colour infra-red photography. In order to verify the interpretations of the aerial photography, ground information was collected by field teams. Occasionally low-flying aircraft were fitted with "metric cameras with long focal lengths" to collect photographic samples of ground conditions which could serve as checks in the interpretation of the "lower resolution satellite-type photographs".

Probably the greatest interest created by the initial Phoenix quadrangle study has been its association with attempts to construct a versatile classification scheme that could be used in preparing small scale land use maps from orbital imagery. The researchers agreed that, although it was very unlikely that one ideal classification of land use would ever be developed or accepted, there was a definite need for a standardised approach. So, prior to the final construction of their classification they listed certain criteria that should be attained viz

"1. A minimum level of accuracy of about 85% to 90% or better should be approached in the interpretation of the imagery being used.

2. A well-balanced reliability of interpretation for the several categories included in the classification scheme should be attained.

3. Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another.

4. The classification shceme should be useable or adaptable for use over an extensive area.

5. The categorisation used in the classification scheme should permit vegetative and other cover types to be related to activity-oriented categories whenever possible.

6. The classification scheme should be suitable for use with imagery taken at different times during the year.

7. The classification scheme should permit effective use of sub-categories that can be obtained from ground surveys or from the use of imagery available at a larger scale or with the use of colour photography.

8. A need to collapse the categories of the classification scheme into a smaller number of categories must be recognised.

9. Comparison with land use information compiled at earlier points in time and with data that will be collected in the future should definitely be possible.

10. The classification scheme should recognize the multiple-use aspects of land use whenever possible".

Detailed explanations of these criteria ~~has~~ have been reported in a separate article (Anderson, 1971).

A land use classification scheme for the Phoenix area was then established and it was evaluated against the suggested criteria and, although some criteria could not be satisfied immediately, the overall scheme worked satisfactorily. The researchers concluded that land use maps "of reasonable accuracy and quality" could be compiled at a scale of 1:250,000 from orbital imagery and that "agreement on a framework or scheme of land use classification for use with orbital imagery will be necessary for effective use of land use data". This desire for a satisfactory scheme was virtually fulfilled when a Land Use Classification System for use with Remote-Sensor Data was presented in U.S. Geological Survey Circular 671 (Anderson, Hardy and Roach, 1972). The system was designed so that it could be used with remote sensing imagery with minimal reliance on supplementary information at two generalised levels of categorisation (ie. Level 1 and Level 2) (see Tables __ and __). Also, a modified list of criteria which the system should meet based on those previously proposed by ~~Alexander~~ Anderson and Place was included in the Circular. A more detailed discussion of this classification system is presented in the next chapter (see)

Later investigations in the Phoenix quadrangle were primarily designed to test and verify the validity of the land use classification system proposed in U.S.G.S. Circular 671 as well as analysing the applicability of Landsat imagery for detecting land use changes and up-dating maps (Place, 1974). Landsat 1 9" x 9" 1:1,000,000 transparencies were interpreted using a range of techniques including the use of colour composites and an I^2S colour additive viewer to create a number of specific colour composites using selected spectral bands at different time periods. After testing many techniques the researchers claimed that the best method of distinguishing land use change was by making seasonal comparisons of Landsat colour composites using bands 4, 5 and 7.

Another study initiated by the Geographic Application Program of the U.S. Geological Survey has been reported by Alexander (1973a) who described the use of Landsat colour composite images in a preliminary study of land use classification and land use change in the Central Atlantic Regional Ecological Test Site (CARETS). Significant land use changes were identified using conventional visual interpretation techniques and enlargements of the colour composites in association with 1:100,000 maps produced from 1970 high altitude photography. These results were achieved after the interpreter familiarised himself with the principal visual signatures of the various land use types as they appeared on the enlarged Landsat imagery. Land use classification was based on the U.S. Geological Survey Land Use Classification System (U.S.G.S. Circular 671) and the interpreter attempted to classify the existing land use to second order ~~level~~ of accuracy, ie. Level 2. Attempts were then made "to verify whether charges had actually occurred and whether the correct interpretations of that change had been made" by utilising the 1972 Landsat underflight (U-2) photography of the area. The researchers considered that the results of the land use change analysis was highly promising even without employing more sophisticated spectral signature techniques that was possible with the Landsat multi-spectral data. They also claimed that the high proportion of Level 1 and 2 land use was detected and identified correctly.

In another associated investigation LANDIFT ~~Landsat~~ imagery of the CARETS region was examined at a variety scales ranging from contact prints of 70 mm film chips ~~clips~~ supplied by N.A.S.A. (scale 1:3,600,000) to enlargements up to 1:100,000 (Anderson, 1973b). One procedure that was found to be useful for a regional overview was the production of an uncontrolled mosaic from enlarged prints of band 5 imagery at 1:1,000,000. A zonal map based on visible tones and textures on the mosaic was constructed and the patterns were compared with

TABLE : A LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA (U.S. Geological Survey Circular 671; U.S. Department of the Interior, 1972)

Prepared by: J.R. Anderson, E.E. Hardy, J.T. Roach

Level 1	Level 2
1. Urban and Built-up Land	1. Residential 2. Commercial Services 3. Industrial 4. Extractive 5. Transportation, Communications, and Utilities 6. Institutional 7. Strip and Clustered Settlement 8. Mixed 9. Open and Other
2. Agricultural Land	1. Cropland and Pasture 2. Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas 3. Feeding Operations 4. Other
3. Rangeland	1. Grass 2. Savannas (Palmetto Priaries) 3. Chaparral 4. Desert Shrub
4. Forest Land	1. Deciduous 2. Evergreen (Coniferous and Other) 3. Mixed
5. Water	1. Streams and Waterways 2. Lakes 3. Reservoirs 4. Bays and Estuaries 5. Other
6. Unforested Wetland	1. Vegetated 2. Bare
7. Barren Land	1. Salt Flats 2. Beaches 3. Sand other than Beaches 4. Bare Exposed Rock 5. Other
8. Tundra	
9. Permanent Snow and Ice Fields	

TABLE : TENTATIVELY PROPOSED REVISIONS FOR A LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA (U.S.G.S. Circular 671)

Prepared by: James R. Anderson, Chief Geographer, U.S. Geological Survey; October, 1973

Level 1	Level 2
1. Urban and Built-up Land	1. Residential 2. Commercial and Services (including institutional) 3. Industrial 4. Extractive (excluding strip mining, quarries, and gravel pits, etc.) 5. Transportation, Communications, and Utilities 6. Mixed (including strip and clustered settlement) 7. Open and Other
2. Agricultural Land	1. Cropland and Pasture 2. Orchards, Groves, Vineyards and Ornamental Horticultural Areas 3. Confined Feeding Operations 4. Other
3. Forestland	1. Deciduous 2. Evergreen (coniferous and others) 3. Mixed
4. Wetland	1. Forested 2. Non-forested
5. Rangeland	1. Herbaceous Range 2. Shrub-Brushland Range 3. Mixed
6. Water	1. Streams 2. Lakes 3. Reservoirs 4. Bays and Estuaries 5. Other
7. Tundra	(Proposed level-2 categories are currently under study in Alaska and will be reported separately)
8. Permanent Snow, Icefield, and Glaciers	(Proposed level-2 categories are currently under study in Alaska and will be reported separately)
9. Barren Land	1. Salt Flats 2. Beaches (including mudflats) 3. Sandy Areas other than Beaches 4. Bare Exposed Rock 5. Strip mines, quarries, and gravel pits 6. Transitional Areas 7. Other

(from Third ERTS Symposium, N.A.S.A., 1974, pp. 31-32) existing small scale maps of the region representing relief, land surface forms, geology, soils, vegetation, forest types and land use. As mentioned previously, it was found that the zones located on the LANDSAT mosaic most closely resembled the patterns on the existing small scale land use map. This discovery supported the hypothesis of the CARETS investigators that remote sensor derived data sets on land use and land use change should become the basis for a regional information system which could serve the needs of regional planners and land managers.

Many other studies have been independently initiated throughout the United States and land use maps with various scales and/or classification systems have eventuated. In Nebraska, a 7 colour 1:1,000,000 scale, Level 1 general land use map was produced during the summer of 1973 for the State Office of Planning to assist in the preparation of recommendations for land use planning regulations (Carlson et al, 1974). A larger scale 1:62,500 Level 2 supplementary land use map was also produced in a pilot study using aerial photographs. It is interesting to note that no reported attempt was made to utilise LANDSAT ~~Landsat~~ imagery at Level 2 classification. The major purpose of the small scale map was "to be a tool for orientation and for visual impact of both the land use data and remote sensing applications. This was achieved by considering LANDSAT ~~Landsat~~ imagery at 1:250,000 scale and then reducing ~~reduced~~ to 1:1,000,000. The major interpretation technique involved the use of colour additive viewer with various filter and spectral band combinations in order to enhance certain categories. No details of ground truth procedure used in the production of the small scale map were provided but the authors stated that after field checking the map was found to be 90% accurate.

Brown et al (1973), University of Minnesota, in cooperation with regional, State and Federal agencies associated with land management responsibilities, examined LANDSAT ~~Landsat~~ 1 imagery to determine its suitability for satisfying some of the land use data needs in their state. They developed land use class definitions that could be operationally employed within the overall framework of the existing Minnesota Land Management

System. They distinguished four broad areas of land use in their test site and did not consider the guidelines provided by U.S.G.S. Circular No. 671. However, before they made their final detailed classification they consulted local and State land and resource management authorities regarding their information needs. Overall, they found that the potential of the Landsat imagery as a basis for mapping land use information was beyond their expectations and that, by using high quality imagery at appropriate seasons of the year, their unsophisticated techniques yielded much more detailed land use detail than existed at that time. This they claimed was achieved in their state which was already regarded as a leader in the field of land management. The main interpretation procedures involved the use of 70 mm positive transparencies which were projected individually or combined in a Mini-Addcol viewer. The colour combined schemes were photographed and projected for interpretation at scales ranging from 1:250,000 to 1:30,000. Later experimental analyses included an image analyser which provided density slices from 1:1,000,000 positive and negative transparencies. The authors stated that ground truth procedures were carried out to support their investigations and that they were based on field investigations and a variety of aerial photographs but did not elaborate.

Sweet et al (1974) have used LANDSAT 1 and Skylab imagery in association with conventional and multi-spectral underflight photography and radio metric ground observations in experimental studies using a wide range of interpretation techniques. A wide range of interpretation equipment has been available including a multi-spectral viewer and density slicing colour viewer with built-in electronic planimeter. LANDSAT 1 MSS data was received periodically in 70 mm, 24 cm x 24 cm imagery and digitised tape formats. After this investigation, they concluded that N.A.S.A. satellites could provide the data necessary for comprehensive and routine inventorying and mapping of Ohio's natural and cultural features at scales of 1:24,000 and smaller at less cost and with better accuracy than with previous techniques. They have used the U.S. Geological Survey Circular No. 671

Land Use Classification as the basis for their land use surveys.

Researchers at University of California, Riverside also found that ~~Landsat~~ LANDSAT 1 imagery has great potential for monitoring land use change as well as a data source for future regional planning in the Northern Coachella Valley, California (Bale and Bowden, 1973). Their research was activated by the concern of Federal and State agencies who wanted to monitor the effects of the recreational pursuits of people from the heavily populated coastal plain on the sensitive arid environment. ~~Landsat~~ LANDSAT 1 imagery was used as the primary data source and high altitude photography was obtained from U-2 and RB-57 flights to assist in interpretation and field work. Land use classification was based on previous conventional surveys. Most of the mapping was accomplished using enlarged positives or projected slides taken from images previously projected onto the screen of an additive viewer using bands 4, 5 and 7. Two different formats of Landsat 1 imagery were used in the viewer to produce false colour images. Selected portions of 24 x 24 cm 1:1,000,000 positive transparencies and complete 70 mm 1:3,360,000 positive transparencies were used with various filters. The use of the enlarged selected portions of the larger scale transparencies allowed viewing on the view plate at approximately 1:150,000 but provided less resolution than the 70 mm transparencies. Further enlargements up to 1:62,500 for the actual mapping processes was achieved by producing positive enlargements or by projecting slides of portions of the reconstructed image on the colour viewer view plate. The researchers claim that "resolution usually extended to 80 acre $^1/_8$ sections" (approx. 33 hectares) but was better where intense spectral signatures were associated with specific uses. Ground truth procedures were carried out to verify the type and amount of land use change and it was found that there were only two cases where the land use had been misinterpreted but overall the location of boundaries could not be determined accurately. Several factors that influenced the quality and resolution of land use information obtained during the investigation were listed, viz the scale of the final map, the availability of secondary data sources, the expertise of the interpreter and how well he knows the area.

In addition to the general trend of complimentary remarks about the ability of Landsat imagery to provide valuable data for the preparation of satisfactory bases for regional planning, groups of researchers have emphasised how the imagery can permit the rapid production of small scale land use maps. For example, Lindgren and Simpson (1973) produced an 11-category map of Rhode Island in 8 man-days but they did not discuss the operational procedures. However, they claim that the maps displayed considerable accuracy when compared with maps compiled from high altitude aircraft imagery. Also, in the previously mentioned investigation by Estes, Thaman ~~Thoman~~ and Senger (1974) they reported that they produced an 8-category land use map of the Central Coastal Region of California in 7 man-days (an area of 52,213 sq. km).

3.2.3. LOW COST AND UNSOPHISTICATED TECHNIQUES

It is apparent that few research projects have been undertaken in the United States specifically to investigate unsophisticated and inexpensive land use mapping techniques. One interesting investigation by Hardy, Skaley and Phillips (1974) of Cornell University was carried out to develop a low cost, manual techniques that could be used to enhance LANDSAT 1 imagery and to prepare it "in suitable format for use by users with wide and varied interests related to land use and natural resources information". They asserted that "experience has shown that the more sophisticated the method of processing resource information, the smaller is the number of potential users of that information". They believe that this situation is mainly due to the fact that most local officials associated with resource management decisions "do not feel at ease with, or trust, information prepared in a manner they themselves cannot accomplish or duplicate". Therefore, they have directed their investigations towards low cost, manual interpretation techniques incorporating photographic processes.

During the initial stages the researchers experimented with films and filters to provide a more balanced density range of the 70 mm Landsat film ~~clips~~ chips. This permitted the imagery to be enlarged to scales of 1:150,000 or larger with better spatial resolution. Positive transparencies carefully prepared from the negatives were then run through the diazo process and any of the spectral bands could be produced in cyan magenta or yellow. When band 4 (yellow), band 5 (magenta) and band 7 (cyan) were printed and superimposed they produced high quality false colour images. Enlargement of the false colour images to scales as large as 1:66,000 were made and the ~~recorders~~ researchers claim that information for land use classification could still be interpreted.

Other experiments have been carried out by Hardy, Skaley and Phillips and they assert that "although work needs to be continued on the development of a prediction model of the possible combinations colour and what they relate to, we have been able to identify any land use information by isolating it in a colour of unique contrast with its surrounding areas". Furthermore, they claim that the prepared imagery has high resolution capabilities and boundaries between contrasting colours and hues are sharp. They also maintain that this imagery can be used for the direct transfer of data at scales of 1:250,000 (with map units of approx. 25 hectares) to 1:150,000 or larger and with projection techniques and inexpensive equipment it can provide excellent results at 1:24,000 or larger. Also, they have suggested a simple procedure for data extraction, viz.

"1. Prepare a base map at the desired scale with a few geographic references such as lakes and stream".

2. Trace regions of ~~Lake hue~~ like hue identified as homogenous spectral category onto the overlay.

3. Construct a spectral map from different composite~~d~~s to fill in the desired information for the mapped area.

4. Relate areas to Universal Transverse Mer~~f~~cator coordinates and record on appropriate forms for computer storage and retrieval.

The ~~occurring~~ accuracy of this procedure was verified by comparison with low altitude photographs, existing land use surveys and field checking and results have shown "a high degree of correlation, usually close to or over 90%". The researchers have found this technique very useful for up dating previous inventories, analysis of seasonal change, compilation of new maps eg. forestry and agriculture, the isolation of one specific land types or land use and that it has been used by planning agencies and number of state agencies. The claimed advantages of the system are its low cost, high accuracy levels wide selection of operational scales, the material is readily understood and that it does not require expensive and sophisticated equipment. They maintain that "the whole process can be carried out anywhere in the world with equipment costs of $10,000 or less". Unfortunately, the last assertion tends to contradict one of the main objectives, viz. a low cost system because the researchers' perception of low cost may not necessarily match the views of researchers in other countries.

It appears that no recent comprehensive review of U.S. investigations that have used unsophisticated techniques to produce small scale rural land use maps has been published. However, Joyce (1974) has presented a concise summary of some interpretation and classification techniques using mainly U.S. examples. He states that conventional visual interpretation of MSS imagery using hues of tone, texture and pattern to define land use has been the most common method used and all Level 1 and many Level 2 categories were identified at acceptable levels. Black and white imagery of individual lands and colour composites constructed mainly from bands 4, 5 and 7 have been the primary data bases and the most satisfactory results have been achieved by interpreting colour composites at scales ranging from 1:1,000,000 to 1:100,000 with 1:250,000 being the most common. He also asserts suitable results have been obtained using simple techniques involving optical magnifying instruments and standard 1:1,000,000 colour composites or by direct visual interpretation of the enlarged colour composite. The most common smallest unit area that has been consistantly identified and measured has been 40 acres (160,000 m^2) whilst some researchers have claimed to have achieved 10 acres (40,000 m^2). A higher degree of classification has been obtained using additive viewers and other more refined enhancement techniques but Joyce point out that they are time consuming and require special equipment and skilled operators. In addition, he maintains that the increase in the number of Level 1 categories that can be identified and the improvement in the level of accuracy does not warrant the marked increase in cost and time. He also uses this argument for most Level 2 categories but he does concede that the colour enhancement techniques can be very beneficial in extracting specialised information not generally required at Level 2. He believes that there are advantages and disadvantages associated with both the visual interpretation and computer based classification systems and that some balanced combination of the two will need to be produced in order to extract the maximum amount of information from the LANDSAT data.

Peterson (1975) has produced a short article designed to assist geographers interested in land use mapping and has suggested certain techniques that could be helpful. He does not suggest any special pre-processing of the data other than the normal "off-the-shelf" material available from N.A.S.A.. He also suggests that the U.S. Geological Survey Circular No. 671 Land Use Classification System could be used in association with a colour coding system proposed by Paludan (1973) at a scale of 1:1,000,000. Essentially the interpretation procedures are unsophisticated and designed for the delineation of categories at the same scale. The author stresses that the use of imagery from different seasons is important for accurate interpretation. No ground truth techniques were presented.

3.2.4. SUMMARY

Overall, the United States researchers have considered a very wide range of techniques in the pre-processing, interpretation, classification and ground truth stages. However, most reports of their studies have only placed emphasis on a few of these aspects. For example, some present detailed accounts of their investigations into pre-processing techniques

(Hardy, 1973; Hardy et al, 1974; Dragg, 1974) or their attempts to classify land use (Nunnally and Witmer, 1968; Anderson and Place, 1971; Anderson, 1971; Anderson et al, 1972). Very few researchers have attempted to give extensive descriptions of ground truth and interpretation procedures although accuracy levels have often been stated. This may have been due to the fact that the very good supply of secondary information in the form of existing detailed land use, and topographic maps as well as low and high altitude photography could have provided much assistance. Or, it may have been felt that these techniques have been adequately reported in other investigations. Therefore, it appears that no published report of any United States investigation can be used to provide adequate guidelines for the production of small scale rural land use maps from LANDSAT imagery using inexpensive techniques.

Probably the major direct contribution of the United States studies has been the development of the land use classification scheme for use with remote sensor data by the U.S. Geological Survey (Anderson, 1971; Anderson and Place, 1971; Anderson et al, 1972; Anderson, 1974) which attempted to standardise land use mapping throughout the U.S.. It seems that this aim has been achieved to a large extent as many of the recent reports have tended to adopt it. However, this may have been due to expendiency on the part of the researchers and they may have merely adopted it for convenience and speed. Also, it may have been caused by the fact that the researcher worked for or may have been sponsored by an organisation that had accepted the scheme. Some researchers, however, have been restricted by an [illegible] scheme that had been established before the U.S. Geological Survey classification was introduced.

In general, U.S. researchers have emphasised that the synoptic overview and the rapidity of data collection have given LANDSAT MSS imagery distinct advantages in small scale land use studies by providing generalised land use information as well as assisting in the monitoring of land use changes. But the reasons for the level of accuracy in the final maps have often been attributed to different factors by different researchers. Some of the factors that have been emphasised include the final (or completed) scale of the map (Hardy et al, 1974; Nunnally, 1974), the time of acquisition of the imagery (Place, 1974; Carlson et al, 1974; Peterson, 1975), the interpreter's knowledge of the area (Bale and Bourden, 1973; Estes et al, 1974; Nunnally, 1974), the spatial resolution of the imagery (Hardy et al, 1974; Lins and Milazzo, 1972; ~~Tharman~~ Thamon, 1974), the nature of the classification system (Nunnally and Witmer, 1968; Anderson, 1971) and the type of pre-processing system available (Joyce, 1974; Estes, 1974).